An ecological dynamics rationale to explain home advantage in professional football

GAMA, José, DIAS, Gonçalo, COUCEIRO, Micael, PASSOS, Pedro, DAVIDS, Keith <http://orcid.org/0000-0003-1398-6123> and RIBEIRO, João

Published version

GAMA, José, DIAS, Gonçalo, COUCEIRO, Micael, PASSOS, Pedro, DAVIDS, Keith and RIBEIRO, João (2016). An ecological dynamics rationale to explain home advantage in professional football. International Journal of Modern Physics C, 27 (09), p. 1650102.

AN ECOLOGICAL DYNAMICS RATIONALE TO EXPLAIN HOME ADVANTAGE IN PROFESSIONAL FOOTBALL

JOSÉ GAMA
Faculty of Sport Sciences and Physical Education, University of Coimbra, Portugal, e-mail address: josemiguelgama@hotmail.com

GONÇALO DIAS
Faculty of Sport Sciences and Physical Education, University of Coimbra, Portugal, e-mail address: goncalodias@fcdef.uc.pt.

MICAEL COUCEIRO
Ingeniarius, Ltd., Portugal, e-mail address: micael@ingeniarius.pt.
Artificial Perception for Intelligent Systems and Robotics (AP4ISR),
Institute of Systems and Robotics (ISR), University of Coimbra, e-mail address: micaelcouceiro@isr.uc.pt.

PEDRO PASSOS
CIPER, Faculty of Human Kinetics, Technical University of Lisbon, Portugal, e-mail address: ppassos@fmh.ulisboa.pt.

KEITH DAVIDS
Centre for Sports Engineering Research, Sheffield Hallam University, UK, e-mail address: k.davids@shu.ac.uk.

FiDiPro Programme, Faculty of Sport and Health Sciences, University of Jyväskylä, Finland, e-mail address: k.davids@shu.ac.uk.

JOÃO RIBEIRO
Faculty of Sports Sciences and Physical Education, University of Porto, Portugal, email address: joaoribeiro1907@hotmail.com.

Abstract

Despite clear findings, research on home advantage in team sports lacks a comprehensive theoretical rationale for understanding why this phenomenon is so compelling. The aim of this study was to provide an explanatory theoretical rationale in ecological dynamics for the influence of home advantage observed in research on professional football. We recorded thirty, competitive matches and analysed 13958 passes, from one highly successful team in the Portuguese Premier League, during season 2010/2011. Performance data were analysed using the Match Analysis Software – Amisco® (version 3.3.7.25), allowing us to characterize team activity profiles. Results were interpreted from an ecological dynamics perspective, explaining how task and environmental constraints of a competitive football setting required performers to continuously co-adapt to teammate behaviours. Despite slight differences in percentage of ball possession when playing home or away, the number of passes achieved by the team, while in possession of the ball, was quite different between home or away venues. When playing at home, the number of passes performed by the team was considerably higher than when playing away. The explanation proposed in this study for a home advantage effect can be understood from studying interpersonal coordination tendencies of team sports players as agents in a complex adaptive system.

Keywords: professional football, home advantage, ecological dynamics, interacting constraints, co-adaptation.

Corresponding author: *Faculty of Sport Sciences and Physical Education (FCDEF.UC.), University of Coimbra, Estádio Universitário de Coimbra, Pavilhão 3, 3040-156 Coimbra, Portugal Portugal, Tel + 351 239 802770, Fax+ 351 239 802779,* ***e-mail:*** *josemiguelgama@hotmail.com*

1. INTRODUCTION

Ecological dynamics explains how interactions between performers in team sports, and information from a performance environment, constrain emergent competitive performance behaviours[1-2]. This theoretical approach to game analysis focuses on functional variables that reveal players' adaptive behaviours during their continuous interactions in performance[3-4]. Ecological dynamics has emphasised a constraints-based framework to provide insights on how intra-team coordination tendencies in sports teams can be shaped by different task and environmental constraints in performance[2, 4].

From this perspective, match venue (home or away) provides a powerful environmental constraint which can influence team performance behaviours, shaping important adaptations to team playing styles[5-7]. In this paper we elucidate this theoretical framework to provide a conceptualisation for analysing intra-team behaviours constrained by match venue variations. This approach goes beyond traditional observational methodologies and game analyses, which are somewhat operational in nature. Given what is actually known about team sports dynamics, it is important to not simply quantify actions and game events in a notational manner (e.g., record frequency counts of number of passes, shots and crosses made by a team).

Previous research in football has indicated that playing at home or away may influence the performance of a team[8-17]. These findings have typically been operationalised by statistically verifying factors associated with specific performance outcomes according to game venue. This operational tendency may explain why, in some previous work, home advantage has been described as a multifactorial phenomenon with many unknown aspects[18]. Clearly, there is ar need for a theoretical rationale to develop understanding, frame further research questions and design practice task constraints in training.

Home advantage for a team has been defined with the criterion of over 50% of total points obtained in a competition being obtained when playing at home, in a balanced schedule of matches played at home and away. In this study, home advantage was corroborated by the team under analysis winning 27 and drawing 3 matches. In studies by Courneya & Carron[16] and Brown et al.[19], location factors, including familiarity with playing facilities, distance travelled to a game, game importance, among others were operationally defined as shaping home advantage effects. Home advantage has also been related to other operational factors including familiarity with a field and stadium[20-21] and a more supportive audience for the team playing at home, the so-called 'crowd effect'[22-24].

Until now, there have been no attempts to study home advantage from the paradigm of complex systems with primary performance measures like number of successfully completed passes and percentage of ball possession. An ecological dynamics approach could be useful to explain how match venue might act as a powerful environmental constraint which shapes players' interactive behaviours in different ways during competition. This theoretical perspective proposes that different interacting constraints yield different affordances which invite players' behaviours and interactions with others in their vicinity on field, i.e., teammates and opposing players[1, 25-26]. The term 'affordances'[27] specifies the landscape of opportunities for action (such as passing, shooting, dribbling with the ball) provided in each specific game to each player[3].

According to Bruineberg and Rietveld[28] the way that each individual engages with this landscape of affordances or invitations to perform different actions may provide an 'optimal grip' on the performance environment. The optimality of the 'grip' reflects the nature of control in embedded situations in a performance environment, which may be reflected in the specificity of the interactions that are undertaken by each player and each team when playing home or away. To clarify, it could be argued that, when a football team plays at home, key task and environmental constraints are likely to have a dominant impact in regulating players' behaviours in a distinct way compared to when the competition venue is away[1]. The level of fans' support, the familiarity of dimensions and characteristics of the field, the nature of continuous interactions that emerge from players (dribbling, passing, shooting at goal), and the consequential effects on confidence and motivation levels, act as key interacting informational constraints that continuously shape players' decisions and actions, including the way that they co-adapt to the behaviours of teammates and opponents.

The influence of match venue as an environmental constraint could also be analysed on different time scales (i.e., not just from match to match). The theoretical rationale for this proposed scale of analysis is based on players' co-adaptive behaviours predicated on the nonlinearity that characterizes their continuous interactions in team sports [for a review of evidence see[26, 29]. This interpretation of interpersonal interactions signifies that environmental constraints may influence players' behaviours differently during a football match, as well as between competitive games.

Therefore, we hypothesized that the way players interact throughout a single competitive match will also be affected by whether they are playing home or away. How might these interacting task and environmental constraints shape the 'optimal grip' of a player or sports team? For instance, the effect of enhancing the 'optimal grip' on the performance environment[28] may explain why there is a tendency to increase the frequency of individualised actions in players of teams playing at home[30].

Previous research has indicated that the advantage of playing at home can influence maintenance of ball possession and also increase the frequency of passes successfully performed during a competitive match[31-36]. A study by Taylor et al.[38] revealed associated effects over a season, which suggested that caution should be taken when extrapolating findings from one time period to another. Also, the findings of this study highlighted the complex nature of football performance under differing contexts and outlined the need to consider the influence of situation variables upon tactical performance indicators. Theoretically, the affordances of a team playing home are considerably different than when playing away due to the different environmental constraints that were noted earlier. Previous research has indicated that in home games, there are greater affordances for technical actions like passing and shooting**,** since the players are likely to be more confident playing on a pitch that they are familiar with, in terms of visual characteristics[30, 32, 37].

On the other hand, Gomez et al.[36] argued that constraints when playing at home may give rise to riskier decisions by players. This is because these affordances may vary from player to player, and from match to match, i.e., as a match unfolds. These affordances are dynamic and may be both individual (e.g., invitations for each player) and collective (e.g., for the team as a whole), emerging due to various intrinsic and extrinsic factors governing intra-team collective behaviours[38]**.**

Therefore, the optimal grip provided by affordances when playing at home is likely to significantly increase the number and timing of passes, as well as shots, in certain areas of the field, e.g., midfield or lateral[32-33, 35, 39], not only because of a previously defined team strategy implemented by the coach, but also due to each player's own initiative constrained by opposition behaviours[31, 32].

In this study we developed predictions, based on an ecological dynamics theoretical rationale, for interpreting how match venue would affect performance behaviours of professional football teams. The aim of the current case study was to analyse the constraints of home advantage on players' interactive behaviours in a professional football team on different time scales (between- and within-matches). For that purpose, we sought to analyse data on ball possession and passing accuracy as performance outcome measures (i.e., the difference between successful and unsuccessful passes) in different areas of the pitch during competitive performance. This analysis was performed from match to match but also for blocks of 15 minutes within each match. Variability of passing accuracy was proposed as a suitable indicator of players' adaptive behaviours, which were predicted to differ according to match venue.

2. METHODS

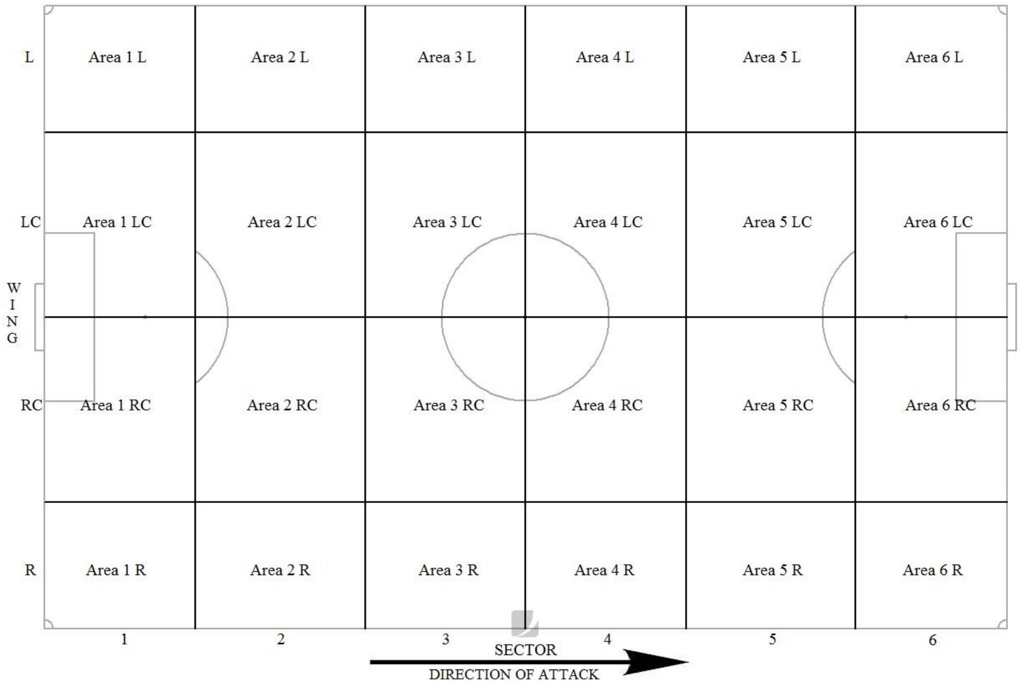
We observed data from 30 matches and analysed 7529 collective offensive actions, from the beginning of ball possession to the moment when the ball was lost. We analysed 13958 passes in total, including: i) passes made with the feet; ii) passes with/to the head; iii) passes made with other parts of the body; iv) throw-ins; and v) when the ball was reset in play from the hands of the goalkeeper. All data in the case study were analysed from matches involving one single professional football team during competitive matches in the Portuguese Premier League in the 2010/2011 season.

Performance data were analysed using the *Match Analysis Software – Amisco*® (version 3.3.7.25), a specialized program allowing us to characterize activity profiles of players in the team. This system captured data over the course of the match in digital video footage obtained from fixed multiple cameras positioned strategically to cover the entire pitch[40-42]. Simultaneously, a trained operator coded each technical action involving the ball, providing *a posteriori* information on various types of actions performed in the game[43-46].

3. PROCEDURES

To quantify the frequency of the number of successful and unsuccessful passes we performed a notational analysis of team performance during attacking phases of play for each match. For that purpose, we set criteria that defined a pass as successfully performed if the ball was subsequently received by a teammate. In contrast a pass was rated as unsuccessful when an interception by an opponent occurred or when the ball left the field of play. A pass was categorised as 'unsuccessful' when a player performed a passing action and the ball was intercepted by a player in an opposing team. The field cell where a given pass occurred was recorded as the location where the player who performed the passing action was positioned at the instant of the pass (see Figure 1 below).

Next we quantified the number of passes performed by the team. After that we recorded the playing field areas where the passes were performed. An *Amisco®* software feature automatically divided the football field into 24 areas, composed of 4 corridors and 6 areas (Figure 1).



Legend: L – Left; LC – Left Centre; RC – Right Centre; R - Right

Fig. 1.The football field divided into 24 areas (adapted from *Amisco*).

To allow us to compare potential differences between successful and unsuccessful passes completed by a team in each of the 24 areas, according to game venue, a histogram-based analysis in the form of a *heatmap* was created[47]. In contrast to other research studies in the field[47], we considered the differences between the number of successful and unsuccessful passes completed within each cell as the key variable under analysis, and this difference was used to quantify the histogram 'intensity' in each cell. For instance, if a given team was able to successfully fulfil n passes in a specific cell, but also failed to complete the same number of n passes in the same cell, the histogram 'intensity' at that cell would be calculated as zero. The histogram 'intensity' within each cell was used to create a *heatmap* that characterized intra-team tendencies for differences between successful and unsuccessful passes according to game venue

Although cells do not depict the same absolute difference between successful and unsuccessful passes, they have the same relevance in terms of performance evaluation of a given team. Additionally, due to the influence of different task constraints, it was expected that the discrepancy between successful and unsuccessful passes may vary, not only from match to match, but also during the different periods of play during each match[48]. We sought to analyse how this difference varied and whether this variability was shaped by the environmental constraint of game venue. This analysis was undertaken because it builds on existing data from previous studies of variability in technical performance indicators, such as by Bush et al.[49-50], Kempton et al.[51] and Liu et al.[52]. Their work highlighted the performance variability within and between different teams in the Spanish football League (La Liga) as function of home advantage.

In our analysis, Shannon's entropy was used to quantify the variability of differences between the number of successful and unsuccessful passes performed by the team within and between competitive matches[53]. Some previous research has used the measure of Shannon's entropy to record variability of players' running line trajectories during competitive performance[54]. Here, we applied Shannon's entropy to analyse differences between the number of successful and unsuccessful passes within each cell on the calibrated playing field, which we termed *cell intensity*[55].

To apply Shannon's entropy to a generic image, one should consider the histogram entry of intensity value i, h_i, to first retrieve the probability mass function as[56]:

$$p_i = \frac{h_i}{N_c}, \quad (1)$$

wherein N_c is the total number of cells, *i.e.*, $N_c = 24$. Shannon's entropy can then be calculated as[54]:

$$E = -\sum_i p_i \log_2 p_i, \quad (2)$$

Considering a soccer field of $N_c = 24$ cells (Figure 1), Equation (2) returns the entropy values defining the variability of the accuracy of a team's passes, based on the discrepancy between successful and unsuccessful passes in a given cell. High entropy values represent a large amount of variability, which means that the discrepancy between successful and unsuccessful passes within each cell varied, not only from match to match, but also during different periods of a match. On the other hand, low entropy values represent a small value of variability, which means that the discrepancy between successful and unsuccessful passes remained relatively stable across matches. This feature may also mean that the players adopted a rather periodic, or even completely steady state, in passing performance, regardless of whether they were playing at home or away[55].

Shannon's entropy measure quantifies the information of an expected value associated with a discrete random variable[53]. The minimum value of Shannon's entropy then corresponds to perfect predictability (i.e., low variability), while higher values of Shannon's entropy are related to a lower degree of predictability (i.e., high variability)[53]. Since it considers emergent variability over time, the entropy value can be seen as a more general measure of uncertainty when compared to the variance or the standard deviation. Entropy and variance reflect the degree of concentration for a particular distribution, and are rather different measures. While the variance measures the concentration around the mean, the entropy value measures the diffusion of density, irrespective of the location parameter[53]. In our investigation, Shannon's entropy was used as a statistical measure of variability to characterize patterns emerging in differences in successful and unsuccessful passes made by a football team under the environmental constraint of playing at home or away. The measure reflects the variability, or regularity, of pass accuracy within cells of the field, shaped by venue constraints on performance.

4. RESULTS

In 30 matches (15 home and 15 away), 13958 passes were performed by the team under analysis, who recorded a total of 27 wins, 3 draws and 0 losses in those games.

To consider whether ball possession was related to the accuracy of passing (here measured by the absolute frequency of successful and unsuccessful passes), we plotted the number of successful passes; the number of unsuccessful passes; and the differences between them, capturing the percentage of ball possession according to game venue (Figure 2).

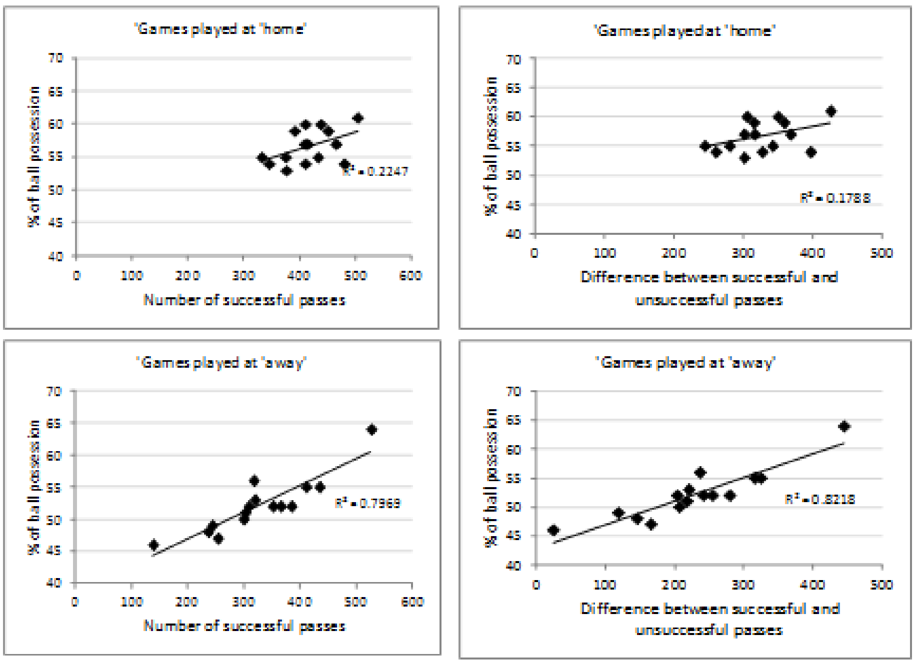


Fig. 2. Relation between passes achievement and ball possession.

Passing accuracy home and away

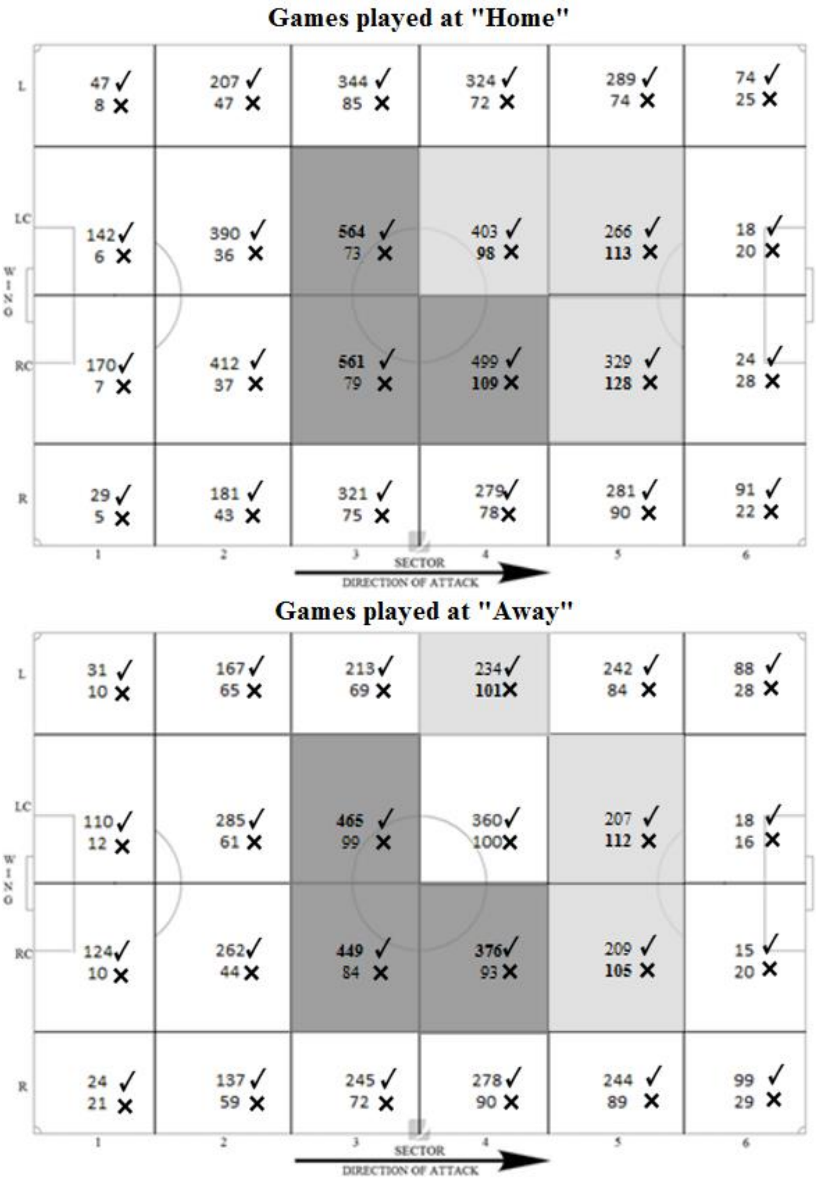
The data indicated that during the season (Table I), the team in this case study performed a higher total number of successful passes at home (54.47%), compared to away (45. 53%).

Table I. Occurrence of the passes (*home* and *away*).

	Passes			
	Home		Away	
	Successfully	Unsuccessful	Successfully	Unsuccessful
Number of Passes	6245	1358	4882	1473
% of Passes	82.14 %	17.86 %	76.82 %	23.18 %
Total Number of Passes in each venue	7603		6355	
% of Passes	54.47 %		45.53 %	
Total sum of Passes (Home and Away)	13958			

The percentage of successful passes was higher during games played at home than in games played away and, as a consequence, the percentage of unsuccessful passes was higher for games played away than for games played at home.

Relating passing accuracy to location on field, Figure 3 identifies the areas of the field where the passes were performed in home and away matches.



Legend: Figure captions: L – Left; LC – Left Centre; RC – Right Centre; R – Right. The grey areas correspond to areas with higher success rate and the light grey areas correspond to passes without success. The number above corresponds to the number of successful passes, identified with a ✓; The number below corresponds to the number of unsuccessful passes, identified with a ✗.

Fig. 3. Location of the passes and areas.

Regarding the total number of passes (i.e., successfully and unsuccessful) completed in home games, the 3RC area in Figure 3 was identified as having the highest incidence of passes (640 passes). In away games the area 3LC (564 passes) displayed the highest number of passes. Both areas are located in the team's own midfield zone. Concerning successful passes for the games at home, the areas 3LC (564 passes), 3RC (561 passes) and 4RC (499 passes) were the areas with the highest occurrences. For away games, the areas 3LC (465 passes), 3RC (449 passes) and 4RC (376) in Figure 3 displayed the highest number of successful passes. All these areas are located in the team's midfield.

Regarding unsuccessful passes made during games at home, the areas 5RC (128 passes), 5LC (113 passes) and 4LC (109 passes) in Figure 3 displayed the highest number of unsuccessful passes. All these areas are located in the opposition's midfield, and the areas 5RC and 5LC are quite close to the opposition's goal. For away games, the areas 5LC (112 passes), 5RC (105 passes) and 4L (101 passes) in Figure 3 displayed the highest number of unsuccessful passes. Again these areas are located in the opposition midfield The area 4L, close to the sideline, was one area characterised by many unsuccessful passes, a tendency quite different from games played at home.

Figure 4 depicts the heatmap of the same team under different environmental constraints, i.e., for games played at home or played away.

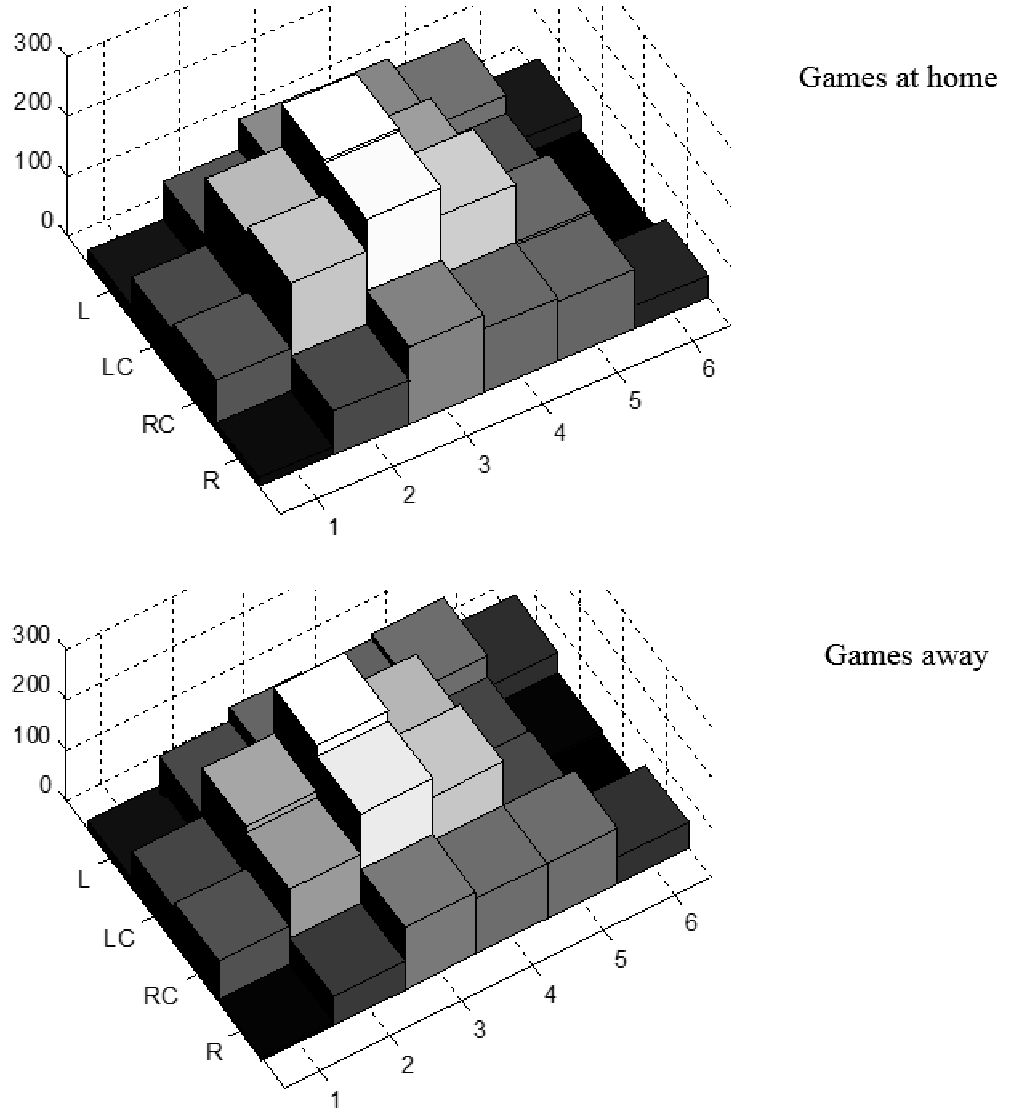


Fig. 4. Heatmaps of relative number of passes (i.e., successful passes minus unsuccessful passes) carried out by the team in the field; 2.a) for games played at 'home'; 2.b) for games played away.

Data from Figure 2 reveal similar relations between performance in games played at home and away. Despite some minor differences, the team's passing performance heatmap displayed the same pattern, regardless of playing at home or not, in which a considerably higher success of passes can be observed in the midfield, more specifically in the area 3LC.

Within each area of the performance field the difference between successful and unsuccessful passes varied between matches, but also within each match. Applying Shannon's entropy measure to these histograms allowed us to characterize the variability of the successful versus unsuccessful discrepancy according to game venue. When playing at home, the team displayed an entropy mean value of the discrepancy between successful and unsuccessful passes of 4.5016, against an entropy value of 4.4183 while playing away. Both values were considered as stochastic and are quite close, highlighting a specific playing pattern, regardless of playing venue[54].

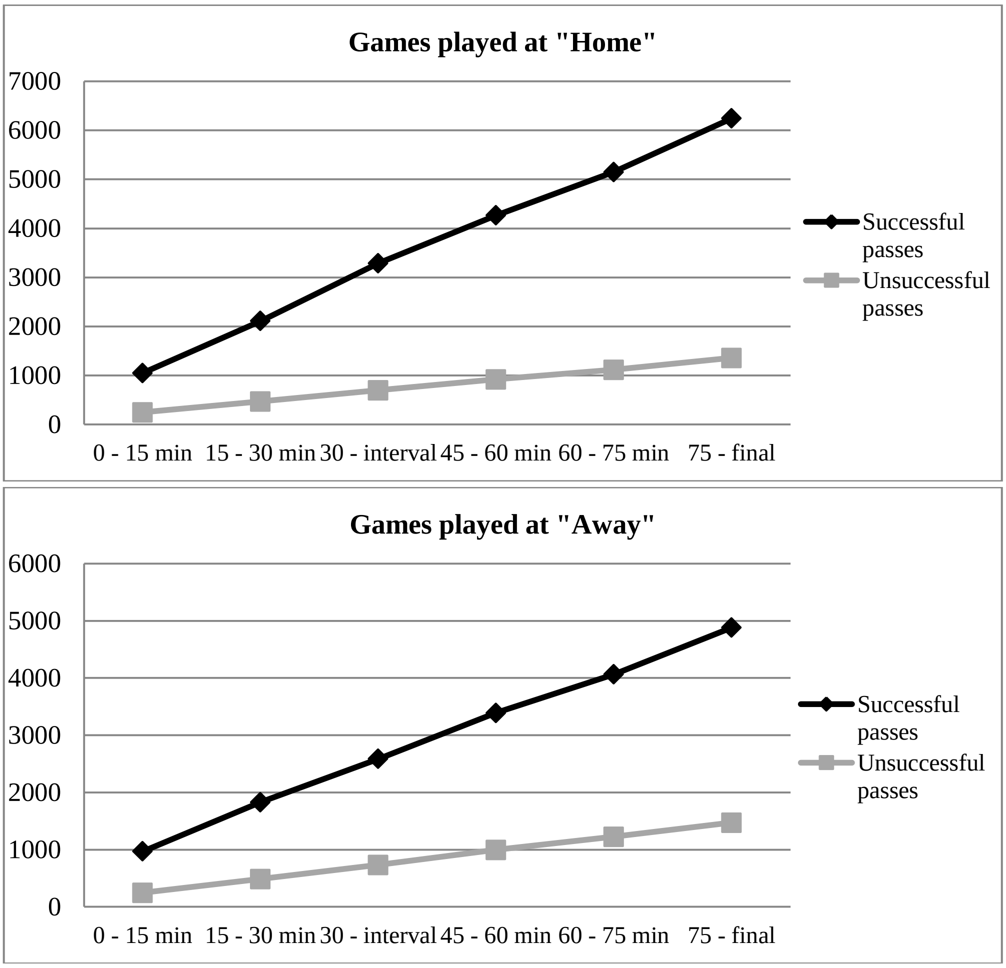


Fig. 5. Mean values of the relative number of passes (i.e., successful passes minus unsuccessful passes), in 15 minute blocks, completed by the team for games played at home and away.

Independent of match venue, by analysing the number of successful and unsuccessful passes in 15-minute intervals, one may observe similar results, where the number of passes (either successful or unsuccessful) gradually increased.

Beyond total mean values for games played at home and away, it was worth analysing how entropy values changed on average during a match constrained by game venue (Figure 6).

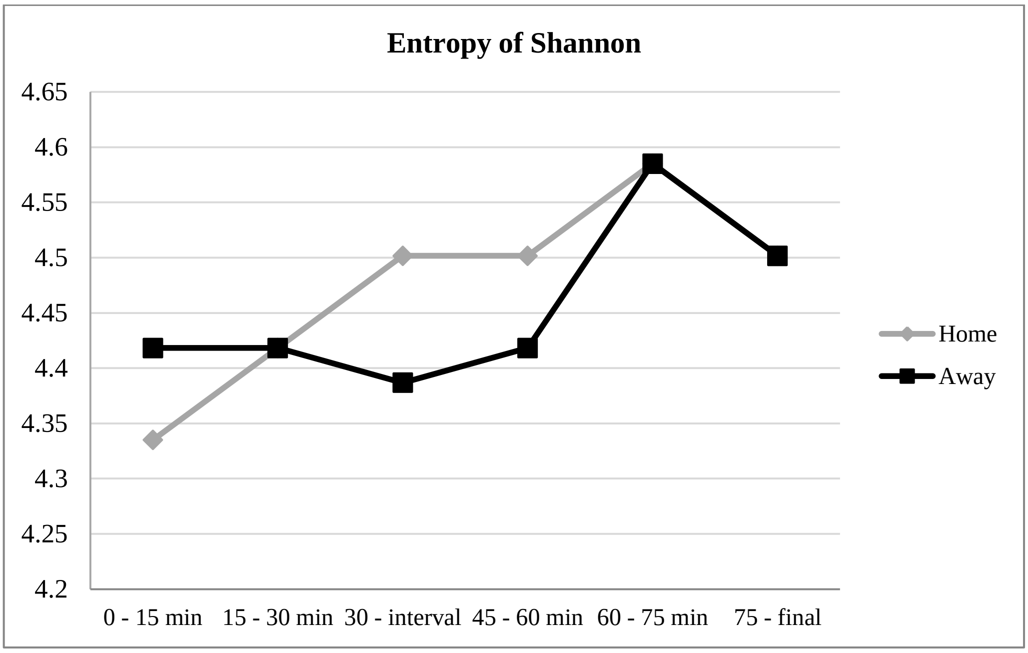


Fig. 6. Mean values of Entropy of the relative number of passes (i.e., successful passes minus unsuccessful passes), in 15 minute blocks, completed by the team for games played at home and away.

Application of Shannon's Entropy in 15-minute time blocks revealed relevant differences throughout the game according to game venue. For example, in the first 15 minutes, entropy values were higher for games played away (4.4183) compared to games at home (4.335). In the second block of 15 minutes, i.e., between 15-30 minutes, entropy measures converged on an identical value at both venues. For the last 15 minutes of the first half entropy significantly increased in games played at home (30 – interval an entropy mean value of 4.5016) and decreases for matches played away (30 – interval an entropy mean value of 4.3868).The games played at home displayed higher entropy values, which remained until the last 15 minutes of the match. The highest entropy values occurred from minute 60 to 75. For the final 15 minutes the entropy values significantly decreased and were similar for both game venues.

5. DISCUSSION

Underpinned by an ecological dynamics rationale to understand interactive behaviours within sports teams during performance[38, 57], this study sought to investigate the constraint of home advantage on an important performance metric (i.e. ball passing) of a professional football team during competition**.** Based on previous research[7, 21, 31, 58-59], we hypothesized that home advantage would be a key constraint significantly influencing the amount of ball possession and the number of passes successfully made during, and within, competitive games that provided players in the team with an 'optimal grip' on the affordances of a competitive performance environment[28]. Our data were in line with previous findings which concluded that key performance variables (e.g., successful passes) are constrained by the home advantage. Our results showed that it is necessary to take into account the interactive effects between environmental and individual constraints that influence *emergent performance behaviours* in understanding how home advantage might constrain performance outcomes[60-61].

When we compared the data from our study with Sasaki et al.,[34] and Tucker et al.[35], the results also partially confirmed that the technical performance indicators may better serve as performance predictors when playing at home than away. Moreover, the team exhibited more successful behaviours (e.g., completing more successful passes) at home than away.

Our data are also aligned with previous research revealing that performance variables, such as ball possession or pass accuracy, are key constraints on successful outcomes. For instance when analysing the World Cup competitions of 1990 and 1994, Hughes and Franks[30] found that teams which spent more time in ball possession created a greater number of passes and shots, increasing their probability of scoring a goal. Also Lago-Peñas and colleagues[62] observed that the ability to retain ball possession and the quality of passing were performance characteristics strongly linked to successful match outcomes in football[62]. Finally, Tempone and Silva[68] analysed 64 games from the 2010 World Cup (excluding the 18 games that ended in draws). They concluded that successful teams displayed a higher proportion of ball possession, which provided a greater offensive capacity throughout the game. Our data, and related theoretical rationale, can be interpreted to suggest that a greater proportion of ball possession may provide a team with an 'optimal grip'[28] on the affordances or opportunities for attacking actions, consequently providing more invitations to score goals, under a given set of environmental constraints, e.g., playing home or away[64].

In this case study, we expected that ball possession would be strongly influenced by passing accuracy. Data revealed different regression values according to game venue: for games played at home passing accuracy only explained 18% of ball possession, whereas for games played away, passing accuracy explained up to 82% of ball possession. These differences in data may reveal how task and environmental constraints can shape the 'grip' that athletes and teams have on the landscape of affordances in a competitive performance environment[28]. An important issue that needs to be discerned in future research from an ecological dynamics rationale is whether the optimality of the grip on the affordance landscape might mean that games played at home might afford the use of more technical individual skills (e.g., dribbling skills) to de-stabilise defences when in possession of the ball. In contrast, in games played away, enhanced ball possession might afford more collective team behaviours sustained on passing and supporting teammates to deprive the opposition of opportunities to build momentum in exploiting home advantage.

Regarding the influence of pass location as a task constraint, both venues revealed the same areas where the highest number of successful passes occurred, within the team's own midfield area (i.e., areas 3RC, 3LC and 4RC). These results supported previous research findings, which revealed that 60% of passes performed in a match occurred in the midfield area of a team (i.e., in the defensive midfield)[41]. One reason for these results is that it was in these areas of the field that recovery of ball possession occurred most often, which afforded initiation of counter-attacking phases of play. It is worth noting the existence of a pattern for the location of passing accuracy, according to both venues, i.e., successful and unsuccessful passes occurred in the same or very close areas. These results are in agreement with previous research revealing that, the closer to the opposition's goal, the lower is the rate of successful completed passes[65-66]. Thus pitch location (i.e., own midfield vs opposition midfield) is a very powerful task constraint that creates different affordances independent of the match venue, which needs to be understood with respect to practice task design.

The heatmaps provided a histogram graphical representation with an estimate of the probability distribution of the data, comprising the difference between successful and unsuccessful passes. Although in absolute terms the team seemed to be able to successfully accomplish a larger number of passes while playing home, the heatmaps showed a pattern that remained approximately the same, regardless of venue. Despite differences in value between successful and unsuccessful passes, according to game venue, the highly successful team selected for analysis displayed the capacity to maintain the same relative performance in passing accuracy. One could argue that this is an adaptive behaviour, in which the team players downscaled their individual coordination tendencies to maintain the collective performance around the same team coordination tendencies[54].

When we scrutinized the amount of successful and unsuccessful passes in 15 minutes intervals, we found that both increased with the unfolding of the game. This qualitative analysis is reinforced through the outcome provided by a variability measure (Shannon's entropy) when applied to the heatmaps. Even though Shannon's entropy values were quite close at home and away venues, they were both classified as stochastic due to their magnitude. This finding signifies that, whether the team was playing home or away, the discrepancy between successful and unsuccessful passes, in all matches, assumed several different values. In other words, the discrepancy between successful and unsuccessful passes in one match was not related to the discrepancy value observed in the previous match. This variability can be seen as a mechanism of players' adaptive behaviours to stabilize performance under task and environmental constraints[55].

A detailed analysis using a short time scale (i.e., by blocks of 15 minutes) displayed different variability values of pass accuracy in accordance with the location of game venue. In games played at home, the last 15 minutes of the first half revealed an increase in risky decisions, which led to an increase in the variability of passing accuracy (*i.e.*, increase in entropy values); whereas for games played away, the decrease in entropy values suggested that usually players make less risky decisions before the break, which led to a decrease in the variability of pass accuracy. This finding supported data from other studies which suggested that the environmental constraints of playing at home give rise to more risky decision making behaviours[36]. After the break, it is worth noting a slight increase in entropy values which suggest that, for games played away, the team adopted more risky behaviours during this initial period of the second half. Based on observations of the highest entropy values for passing accuracy, it seems that the period containing the highest number of risky decisions and actions, regardless of venue, was the second quarter of the second half (between minutes 60 and 75). As the game concluded, and independent of game venue, the team under analysis adopted less risky behaviours as suggested by a decrease in entropy values. These data suggested that playing time is an important task constraint affording different decisions which characterized players' behavioural dynamics, which were also influenced by the environmental constraint of match venue. This finding implies that the same playing time might afford different decisions and actions, (herein captured by the discrepancy between successful and unsuccessful passes whether competitive performance occurs home or away). In further studies this methodology, of investigating whether changing match outcomes can shape home advantage effects, needs to be used considering the match outcome as an independent variable. Additionally we do agree that players' physical conditioning might affect team performance, thus we might also suggest for further research to collect physiological data from where we can infer any issues regarding decreasing of physical performance throughout a competitive the game.

In conclusion, an ecological dynamics rationale provides a potentially powerful theoretical framework for interpreting how the environmental constraint of home advantage might have shaped intra-team behaviours, in this case study of a professional football team, according to variations in match venue. Indeed, our interpretation of the data ventured beyond traditional notational methodologies for game analysis, which provides valuable information but fails to capture dynamical patterns and coordination tendencies in team games. Thus, to understand the influence of home advantage in professional football within an ecological dynamics perspective required us to perform, not only an inter-match analysis, but also an intra-match analysis, to capture the interactive behaviours of the players influenced by different task and environmental constraints[1-3, 67].

Acknowledgments

This research was supported by the *Portuguese Foundation for Science and Technology* (FCT) under the grant SFRH/BPD/99655/2014, *Ingeniarius, Ltd.*, *CIPER*, *Faculty of Human Kinetics*, *Technical University of Lisbon, Laboratory of Expertise in Sport* (*SpertLab*), and *Centre for Sports Engineering Research (CSER)*.

References

1. D. Araújo, K. and Davids, Ecological approaches to cognition and action in sport and exercise: ask not only what you do, but where you do it. *Int J Sport Psychol* **40**(1), 5-37 (2009).

2. K. Davids. Athletes and sports teams as complex adaptive system: A review of implications for learning design. *Rev Int Cienc Deporte* **39**(11), 48-61 (2015). doi:10.5232/ricyde2015.03904.

3. K. Davids, C. Button, S. and Bennett. *Dynamics of skill acquisition. A constraints-led approach*. (Human Kinetics Publishers: Champaign, Illinois, 2008).

4. B. Travassos, K. Davids, D. Araújo, and P. Esteves. Performance analysis in team sports: advances from an ecological dynamics approach. *Int J Perform Anal Sport* **13**, 83-95 (2013).

5. J.R. Bloomfield, R.C.J. Polman, and P.G. O'Donoghue. Effects of score-line on team strategies in FA Premier League Soccer. *J Sports Sci* **23**, 192-193 (2005).

6. R. Pollard, and G. Pollard. Long-term trends in home advantage in professional team sports in North America and England (1876-2003). *J Sports Sci* **23**, 337-350 (2005). doi:10.1080/02640410400021559

7. C. Lago, and R. Martin. Determinants of possession of the ball in soccer. *J Sports Sci* **125**, 959-974 (2007). doi:10.1080/02640410600944626.

8. R. Pollard. Home advantage in soccer: a retrospective analysis. *J Sports Sci* **4**, 237-248 (1986). doi:10.1080/02640418608732122.

9. R. Pollard and R. Charles (1904-2002): pioneer of notational and performance analysis in football. *J Sports Sci* **20**, 853-855 (2002). doi:10.1080/026404102320675684.

10. R. Pollard. World wide regional variations in home advantage in association football. *J Sports Sci* **24**(3), 231-240 (2006). doi:10.1080/02640410500141836.

11. Pollard, R and Reep, C. Measuring the effectiveness of playing strategies at Soccer. *J R Stat Soc Series* **46**, 541-550 (1997). doi:10.1111/1467-9884.00108.

12. Nevill, A.M.; Holder, R.L. Home advantage in sport: An overview of studies on the advantage of playing at home. *Sports Med* **28**, 221-236 (1999).

13. C. Lago and M.R. Acero. Determinantes en el fútbol de alto rendimiento: el tiempo de posesión del balón (abriendo la caja negra del fútbol). *Revista Entren Deport* **19**(2), 13-19 (2005).

14. D.R. Poulter. Home advantage and player nationality in international club football. *J Sports Sci* **27**(8), 797-805 (2009). doi:10.1080/02640410902893364.

15. R. Pollard and M.A. Gomez. Home advantage in football in South-West Europe: Long-tern, trends, regional variation, and team differences. *Eur J Sport Sci* **9**(6), 341-352 (2009). doi:10.1080/17461390903009133.

16. K.S. Courneya, and A.V. Carron. The home advantage in sport competitions: A literature review. *J Sport Exerc Psychol* **14**(1), 13-27 (1992).

17. A.V. Carron, T.M. Loughhead and S.R. Bray. The home advantage in sport competitions: Courneya and Carron's (1992) conceptual framework a decade later. *J Sports Sci* **23**(4), 395-407 (2005).

18. A. Legaz-Arrese, D. Moliner-Urdiales, and D. Munguia-Izquierdo. Home Advantage and Sports Performance: Evidence, Causes and Psychological Implications. *Universitas Psychologica* **12**(3), 933-943 (2013). doi:10.11144/Javeriana.UPSY12-3.hasp.

19. T.D. Brown, J.L. Van Raalte, B.W. Brewer, C.R. Winter, A.E. Cornelius and M.B. Andersen. World Cup soccer home advantage. *J Sport Behav* **25**, 134-44 (2002).

20. A.M. Nevill, S.M. Newell and S. Gale. Factors associated with home advantage in English and Scottish soccer matches. *J Sports Sci* **14**, 181-186 (1996). doi:10.1080%2F02640419608727700.

21. R. Pollard and G. Pollard. Long-term trends in home advantage in professional team sports in North America and England (1876-2003). *J Sports Sci* **23**, 337-350 (2005). doi:10.1080/02640410400021559.

22. S.R. Clarke. Home advantage in the Australian Football League. Jour *J Sports Sci* **23**, 375-385 (2005). doi:10.1080/02640410500074391.

23. S. Wolfson, D. Wakelin and M. Lewis. Football supporters perceptions of their role in the home advantage. *J Sports Sci* **23**, 365-374 (2005). doi:10.1080%2F02640410400021567.

24. R.H. Boyko, A.R. Boyko and M.G. Boyko. Referee bias contributes to home advantage in English Premiership Football. *J Sports Sci* **25**, 1185-1194 (2007). doi:10.1080%2F02640410601038576.

25. P. Passos, K. Davids, D. Araújo, N. Paz, J. Minguéns and J. Mendes. Networks as a novel tool for studying team ball sports as complex social systems. *J Sci Med Sport* **14**(2), 170-176 (2011). doi:10.1016/j.jsams.2010.10.459

26. P. Passos and K. Davids. Learning design to facilitate interactive behaviours in Team Sports. *Rev Int Cienc Deporte* **39**(11),18-32 (2015). doi:10.5232/ricyde2015.03902.

27. J.J. Gibson. *The ecological approach to visual perception*. (Lawrence Erlbaum Associates: Hillsdale, New Jersey, 1979).

28. J. Bruineberg and E. Rietveld. Self-organization, free energy minimization, and optimal grip on a field of affordances. *Front Hum Neurosci 8*, 599 (2014). doi:10.3389/fnhum.2014.00599.

29. P. Passos, D. Araújo and K. Davids. Self-organisation processes in team sports. Implications for leadership. *Sports Med* **43**, 1-7 (2013). doi:10.1007/s40279-012-0001-1.

30. M.D. Hughes and I. Franks. Analysis of passing sequences, shots and goals in soccer. *J Sports Sci* **23**, 509-514 (2005). doi:10.1080/02640410410001716779.

31. D. Forest, J. Beaumont, J. Goddard and R. Simmons. Home advantages and the debate about competitive balance in professional sports leagues. *J Sports Sci* **23**(4), 439-445 (2005). doi: 10.1080/02640410400021641.

32. C. Lago. The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *J Sports Sci* **27**(13), 1463-1469 (2009). doi:10.1080/02640410903131681.

33. J.B. Taylor, S.D. Mellalieu, N. James and P. Barter. Situation variable effects and tactical performance in professional association football. *Int J Perform Anal Sport* **10**, 255-269 (2010).

34. Y. Sasaki, A. Nevill and T. Reilly. Home advantage: A case study of Ipswich Town football club during the 1996-97 season. *J Sports Sci* **17**, 831-840 (1999).

35. W. Tucker, S.D. Mellalieu, N. James and J.B Taylor. Game location effects in professional soccer: A case study. *Int J Perform Anal Sport* **5**, 23-35 (2005).

36. M.A. Gomez, M. Gomez-Lopez, C. Lago and J. Sampaio. Effects of game location and final outcome on game-related statistics in each zone of the pitch in professional football. *Eur J Sport Sci* **12**(5), 393-398 (2012).

37. N. James, P.D. Jones, and S.D. Mellalieu. Possession as a performance indicator in soccer. *Int J Perform Anal Sport* **4**(1), 98-102 (2004).

38. P. Silva, J. Garganta, D. Araújo, K. Davids and P. Aguiar. Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. *Sports Med* **43**(9), 765-72 (2013). doi:10.1007/s40279-013-0070-9.

39. V. Armatas and R. Pollard. Home advantage in Greek football. *Eur J Sport Sci* **14**(2), 116-22 (2014). doi: 10.1080/17461391.2012.736537.

40. C. Carling, A.M. Williams and T. Reilly. *Handbook of soccer match analysis: a systematic approach to improving performance* (Routledge: London, 2005).

41. V. Vaz, J. Gama, J, Valente dos Santos, A. Figueiredo and G. Dias. Network – Análise da Interação e Dinâmica do Jogo de Futebol. *Rev Port Cienc Desporto* **14**(1), 12-25 (2014).

42. J. Gama, P. Passos, K. Davids, H. Relvas, J. Ribeiro, V. Vaz and G. Dias. Network analysis and intra-team activity in attacking phases of professional football. *Int J Perform Anal Sport* **14**, 692-708 (2014). E-ISSN:1474-8185.

43. V. Di Salvo, R. Baron, H. Tschan, F.J. Calderon Montero, N. Bachl and F. Pigozzi. Performance characteristics according to playing position in elite soccer. *Int J Sports Med* **28**, 222-227 (2007). doi:10.1055/s-2006-924294.

44. A. Zubillaga, G. Gorospe, A. Hernandez and A. Blanco, *Comparative analysis of the high-intensity activity of soccer players' in top level competition*. In: T. Reilly and F. Korkusuz. (Eds.) Science and Football VI (Routledge: London, 2009) p. 182-185.

45. C. Carling. Analysis of physical activity profiles when running with the ball in a professional soccer team. *J Sports Sci* **28**, 319-326 (2010). doi:10.1080/02640410903473851.

46. M.B. Randers, I. Mujita, A. Hewitt, J. Santisteban, R. Bischoff, R. Solano, A. Zubillaga, E. Peltola, P. Krustrup and M. Mohr. Application of four different football match analysis systems: A comparative study. *J Sports Sci* **28**(2), 171-182 (2010).

47. F.M. Clemente, M. Santos Couceiro, F.M.L. Martins, G. Dias and R. Mendes. Interpersonal Dynamics: 1v1 Sub-Phase at Sub-18 Football Players'. *J Hum Kinet* **36**(1), 179-189 (2013). doi:10.2478/hukin-2013-0018.

48. Y. Yamamoto and K. Yokoyama. Common and Unique Network Dynamics in Football Games, *PLoS ONE* **6**(12), e29638 (2011). doi:10.1371/journal.pone.0029638.

49. M. Bush, C. Barnes, T.D. Archer, B. Hogg and P.S. Bradley. Evolution of match performance parameters for various playing positions in the English Premier League. *Hum Movement Sci* **39**, 1-11 (2015).

50. M. Bush, D. Archer, R. Hogg and P. Bradley. Factors Influencing Physical and Technical Variability in the English Premier League. *Int J Sports Physiol Perform*, 2015. doi: 10.1123/ijspp.2014-0484

51. T. Kempton, C. Sullivan, J.C. Bilsborough, J. Cordy and A.J. Coutts. Match-to-match variation in physical activity and technical skill measures in professional Australian football. *J Sci Med Sport* **18**(1), 109-13 (2015).

52. H. Liu, M. Gómez and W. Hopkins, Relationships between match events and outcome in football. *Eur J Sport Sci*, 1-10 (2015).

53. C.E. Shannon. A mathematical theory of communication. *ACM SIGMOBILE Mobile Computing and Communications Review* **5**(1), 3-55 (2001). doi:10.1145/584091.584093.

54. M.S. Couceiro, F.M. Clemente, F.M. Martins and J.A.T. Machado. Dynamical stability and predictability of football players': the study of one match. *Entropy* **16**(2), 645-674 (2014). doi:10.3390/e16020645.

55. R.T. Harbourne and N. Stergiou. Movement variability and the use of nonlinear tools: principles to guide physical therapist practice. *Phys Ther* **89**(3), 267-282 (2009). doi:10.2522/ptj.20080130.

56. M.R. Sabuncu and P.J. Ramadge, *Spatial information in entropy-based image registration*. In Biomedical Image Registration (Springer: Berlin Heidelberg, 2003) p. 132-141.

57. D. Araújo, P. Silva and K. Davids, *Capturing group tactical behaviours in expert team players*. In J. Baker and D. Farrow. (Eds.). Routledge Handbook of Sport Expertise (Routledge: London, 2015) p. 209-220.

58. A.M. Nevill, N.J. Balmer and A.M. Williams. The influence of crowd noise and experience upon refereeing decision in football. *Phychol Sport Exerc* **3**, 261-272 (2002). doi:10.1016%2FS1469-0292%2801%2900033-4.

59. J. Bangsbo and B. Peitersen. *Fútbol: jugar en ataque* (Paidotribo: Barcelona, 2003).

60. D. Araújo, A. Diniz, P. Passos and K. Davids . Decision making in social neurobiological systems modelled as transitions in dynamic pattern formation. *Adapt Behav* **22**, 21-30 (2014). doi:10.1177/1059712313497370.

61. D. Araújo, K. Davids, A. Diniz, I. Rocha, J. Coelho Santos, G. Dias and O. Fernandes. Ecological dynamics of continuous and categorical decision-making: The regatta start in sailing. *Eur J Sport Sci* 37-41 (2014). doi:10.1080/17461391.2014.928749

62. C. Lago-Peñas, J. Lago-Ballesteros, A. Dellal and M. Gomez. Game-related statistics that discriminated winning, drawing and losing teams from the Spanish soccer league. *J Sports Sci Med* **9**(2), 288–293 (2010).

63. G.M.T. Tempone and C.D. Silva. Análise de indicadores quantitativos de vitórias e derrotas na Copa do Mundo Fifa 2010. *Rev Bras Futebol* **5**(1), 42-46 (2012).

64. M.A. Riley, B.R. Fajen and M.T. Turvey. Reply to commentaries on "Information, affordances, and the control of action in sport. *Int J Sports Psychol* **40**(1), 207-218 (2009).

65. E. Mombaerts. *Fútbol – entrenamiento y rendimiento colectivo* (Editorial Hispano Europea. Barcelona, Espanha, 1998).

66. E. Mombaerts. Fútbol. *Del análisis del juego a la formación del jugador* (INDE: Barcelona, 2000).

67. K. Newel. *Constraints on the development of coordination*. In M. Hade and H. Whiting. (Eds.), Motor development in children: Aspects of coordination and control (Dordrecht, the Netherlands: Martinus Nijhoff, 1986) p. 3414-360.